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THE U.S. ENVIRONMENTAL PROTECTION AGENCY'S MODEL FOR COMPLEX TERRAIN APPLICATIONS

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ABSTRACT

The Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS), a point-source, steady-state, dispersion model for complex terrain applications, is described and its performance summarized. The model is unique in the manner in which it simulates the flow and plume distortion near the terrain. Emphasis is given to windward side impacts. Simplicity is maintained by applying flow distortion corrections to flat-terrain, Gaussian and bi-Gaussian pollutant distributions.

The performance of CTDMPLUS contrasts with that of a currently-recommended, complex-terrain, regulatory model. In stable or neutral conditions, CTDMPLUS shows relatively small average bias compared to field observations. The root-mean-square differences between CTDMPLUS and the observations are consistently lower and the percent of predictions within a factor of two are significantly higher than those of the regulatory model. In convective conditions, with comparisons unpaired in time or space, CTDMPLUS performs very well.

INTRODUCTION

The Complex Terrain Model Development project was initiated in 1980 by the Environmental Protection Agency to develop an improved plume model for elevated point sources in complex terrain. The primary product of this decade-long effort is the Complex Terrain Dispersion Model Plus Algorithms for Unstable Situations (CTDMPLUS). An early version of the model (CTDM), which was completed and evaluated by Strimaitis et al. (1987), was designed to model plumes released into stable or neutral layers. CTDMPLUS, an extension of CTDM, includes algorithms for modeling plumes released into convectively-mixed layers (Perry et al., 1989).

CTDMPLUS is a point-source, steady-state, dispersion model which estimates hourly-averaged concentrations of plume material on well-defined terrain features. Emphasis is given to simulating flow toward the terrain in which maximum concentrations are expected on the windward side. The terrain is specified as a fully three-dimensional feature about which the model simulates the flow distortion. In the model, the distortion of the flow streamlines influences both the positional relationship between plume and receptor and the rate of diffusion to the terrain surface. Vertical variations in wind speed, wind direction, and turbulence intensities are estimated by interpolation of observations or through surface layer scaling.

In stable or neutral conditions, the structure of the two-layer flow (a concept of Sheppard, 1956, based on energy arguments) is explicit in the formulation. The rate of plume growth depends on turbulence (a function of input velocity fluctuations). For vertical plume growth, the degree of stratification is considered.

For plumes released into daytime convective layers, a probability density function is used to describe the vertical distribution of pollutants. Convective scaling concepts are utilized to parameterize the lateral dispersion. The model considers the effects of terrain-induced flow distortions on pollutant trajectories within the mixed layer and on the height of the mixed layer itself. Buoyant plume penetration into the elevated stable layer above the mixed layer is also modeled.

The CTDMPLUS modeling system is comprised of four major components: the CTDMPLUS transport and diffusion model (Strimaitis et al., 1987; Perry et al., 1989); the terrain preprocessor (Mills et al., 1987), which converts readily available topographic contour information into smoothed terrain features; the meteorological preprocessor (Paine, 1987), which computes surface parameters and mixing depths from on-site tower and surface measurements and from rawinsonde soundings; and postprocessors (Perry et al., 1989), which are available for viewing the predicted concentration patterns on an overlay of the terrain contours. For detailed descriptions of the preprocessors and postprocessors, see the above-mentioned references.

THE CTDMPLUS MODEL

The original model, CTDM (Strimaitis et al., 1987; Paine et al., 1987) was designed primarily to model the important situation of stable-plume impaction on the windward side of the terrain. CTDMPLUS, an expansion of that earlier model, has algorithms to model all stability conditions. The new components were incorporated without alterations to the original CTDM methods.

Pollutant Releases into Stable or Neutral Layers

In stable/neutral conditions, CTDMPLUS retains the Gaussian formulations of CTDM (Paine et al., 1987). When the flow is stably stratified, a two-layer structure develops in which the flow in the lower layer primarily deflects around the sides of the hill, while the flow in the upper layer travels over the hill. The plane of the dividing streamline serves as the boundary between these two layers. This concept was suggested by theoretical arguments of Drazin (1961) and Sheppard (1956) and was demonstrated through laboratory experiments of several investigators, most particularly those of Snyder et al. (1985) for a wide range of flow conditions and terrain shapes.

In the layer above the dividing streamline, the approach flow has sufficient kinetic energy to transport a fluid parcel up and over the hill against the density gradient of the ambient stratification. The centerline of a plume in this flow follows the streamline that passes through the source of that plume. As the plume grows in the vertical and horizontal directions, plume material diffuses across adjacent streamlines, eventually reaching the set of streamlines that marks the surface of the terrain. Distortions in the flow which are induced by the hill change the position and relative spacing of the streamlines and therefore change the shape of the plume as it passes over the hill. As a result, the distribution of surface concentration is altered by the hill induced changes in plume shape, in streamline spacing, and in the rate of diffusion of plume material across the streamlines (Hunt and

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Mulhearn, 1973). Typically, streamline spacing is reduced in the vertical and expanded in the horizontal, while the speed of the flow increases over the hill crest.

In the layer below the dividing streamline, the flow lacks sufficient kinetic energy to surmount the hill and is restricted to travel around the terrain. The flow approximates that which is steady and two-dimensional where only one streamline (the stagnation streamline) at each elevation touches and follows the surface of the hill. Plume material reaches the surface only if it reaches the stagnation streamline. If the plume centerline lies along the stagnation streamline and is below the dividing streamline, the plume center impinges on the hill. If, however, the centerline lies on one side of the stagnation streamline, the center will pass to that side of the hill.

Even though the flow is distorted from the straight line flat terrain case, the plume centerline and each receptor is still associated with a streamline in the flow. Therefore CTDMPLUS parameterizes the plume growth due to turbulence and calculates the effective growth rates and effective receptor positions relative to the undisturbed upwind flow. In this way, the steady-state Gaussian plume formulation is retained while the terrain effects are applied as corrections to the receptor positions and the rates of dispersion.

Figure 1 addresses the plume material above the plane of the dividing streamline. The upper portion of the figure illustrates a vertical cross-section of plume material as it travels over the hill. Beyond the point where the dividing streamline intersects the hill, material below the dividing streamline is separated from that above (and is modeled in another part of the program).

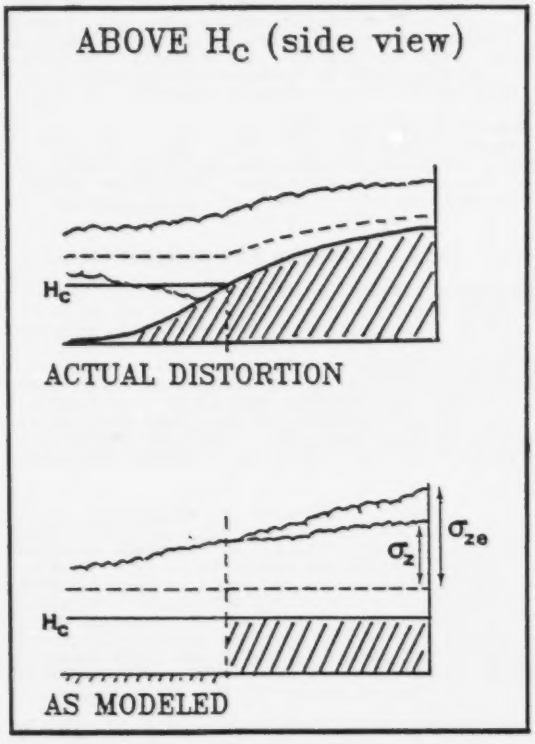

Fig. 1. Depiction of plume behavior as it passes over a hill (hill surface hatched) as seen from the side with flow from left to right. The upper figure shows an example of the actual plume path while the lower figure shows the treatment by CTDMPLUS with all surface level receptors placed on a flat surface of height Hc and the effective vertical plume spread represented by σ_{ze}. σ_z is the vertical plume spread without terrain.

Material above the dividing streamline is distorted in the flow and reflected from the hill surface. The size of the plume in the vertical at downwind distance, s, depends on the amount of distortion in the shape of the plume as well as the amount of additional growth of the plume caused by changes to the rate of diffusion. The lower portion of Fig. 1 illustrates how these processes are treated by CTDMPLUS. The distortion in the flow (and thus the plume) is accounted for in the model by a coordinate transformation, leaving only the effect of the distortion on the diffusion rates; vertical diffusion across streamlines is increased by contraction of the streamline spacing.

Similarly, CTDMPLUS accounts for flow distortions of the lateral dimensions of the plume above the dividing streamline. Adjustments to the receptor location and the lateral diffusion rates are based on the adjusted streamline spacings and the relationship between the streamline passing through the source and that passing through the receptor.

Figure 2 addresses plume material below the dividing streamline. The upper part of the figure illustrates the plume in horizontal cross-section as it splits and flows around a hill. In this

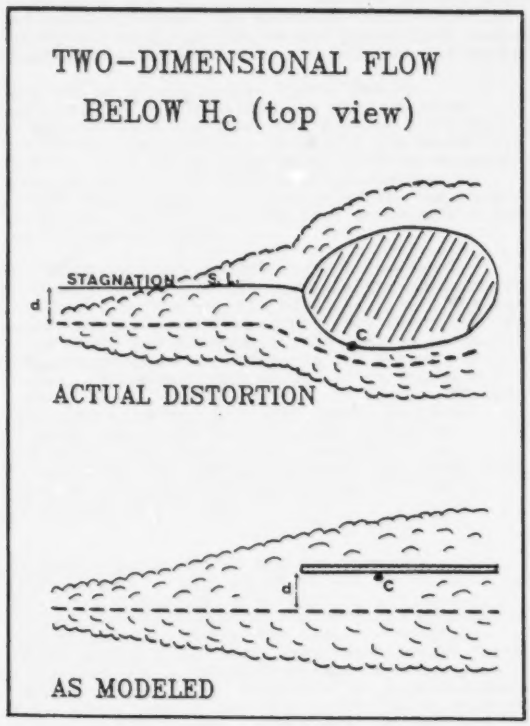

Fig. 2. Depiction of plume behavior as the plume is deflected around a hill (hatched) as seen from above with flow from left to right. The stagnation streamline in the upper figure separates the flow (plume material) going around the two sides of the hill. In CTDMPLUS, the hill is treated as an impenetrable straight wall (lower figure) that separates the flow and the receptors are placed on the appropriate side of the wall. d represents the distance between the source streamline (dashed line) and the stagnation streamline (on which all hill surface receptors reside).

case, some plume material has crossed the stagnation streamline before the hill is encountered, so the plume material will impact on both sides of the hill. As the plume wraps around the leading edge of the hill, the stagnation streamline follows the boundary of the hill, and the hill surface below the dividing streamline reflects plume material as does the surface at z equal to zero. Beyond the initial point of interaction with the hill, the plume is split by the plane of the stagnation streamline and

material cannot diffuse from one side of the hill to the other.

The lower part of Fig. 2 illustrates CTDMPLUS' treatment of this flow. The actual surface of the hill is replaced by a line in the plume that corresponds to the position of the stagnation streamline. All distortion is accounted for in this transformation in much the same way as with the material above the dividing streamline. However, the effect of flow distortion on lateral diffusion is not considered significant in this two-dimensional flow. The lateral positions of all receptors below the dividing streamline essentially collapse onto the stagnation streamline (such as receptor C in the figure), so that each receptor is the same distance from the plume centerline. However, concentrations are different from one side of the line to the other because diffusion through the line (hill) is not allowed.

Above the dividing streamline, the streamline distortions are approximated with a flow algorithm that is based on linearized equations of motion for steady-state Boussinesq flow (Smith, 1980). Approximate solutions to these equations can be obtained for hills with Gaussian-shaped vertical cross-sections (as provided by the terrain preprocessor). Analytical solutions for two-dimensional flow around an ellipse are used to estimate the streamline distortions below the dividing streamline.

The CTDMPLUS formulations for the lateral and the vertical dispersion coefficients in stable/neutral conditions are based on Taylor's (1921) theorem for diffusion for very short and very long travel times and interpolation formulas by others (Deardorff and Willis, 1975). The lateral coefficient is a function of the travel time and the fluctuations in the lateral velocity component. The vertical coefficient, based on work by Venkatram et al. (1984), is a function of height, the travel time, the Brunt-Vaisala frequency, and the fluctuations in the vertical velocity. CTDMPLUS also accounts for plume spread due to the initial buoyancy of the source by adding an appropriate amount to the travel time.

Plume rise for neutral/stable conditions is based on work of Briggs (1975) with CTDMPLUS selecting the lowest rise from formulas for bent-over plumes (stable conditions), high wind speed (neutral conditions), and calm winds (stable conditions).

Pollutant Releases into Convective Layers

The CTDMPLUS algorithms for convective conditions focus on the following areas: 1) buoyant plume penetration into elevated stable layers; 2) a probability density function (PDF) approach to defining the vertical pollutant distribution with corrections to account for terrain induced curved trajectories; 3) terrain adjustments to the mixed-layer depth and the associated flow distortion within the mixed layer; and 4) lateral dispersion based on convective scaling concepts.

Plume Penetration and Plume Rise Plume penetration into the stable layer above the mixed layer is important in its influence on the plume material that is available for surface impact. CTDMPLUS uses an algorithm proposed by Briggs (1984) for estimating the fraction of buoyant plume material that escapes the mixed layer. The penetration factor is a function of the plume buoyancy flux, the potential temperature gradient above the mixed layer, and the difference between the stack height and the mixing height.

CTDMPLUS uses the penetration factor (fraction) to adjust the total plume mass and to adjust the buoyancy flux of the remaining plume material. These adjusted values are used for subsequent model calculations.

Plume rise for unstable/neutral conditions is based on work of Briggs (1975) with CTDMPLUS selecting the lowest rise based on formulas for final or transitional rise (in the mixed layer), unstable breakup plume rise, touchdown plume rise, and neutral breakup plume rise.

Vertical Distribution Function. Vertical distributions of pollutants downwind of elevated sources in convectively-driven mixed layers have been observed to be distinctly non-Gaussian in convective tank studies (Willis and Deardorff, 1976, 1978, 1981), in numerical modeling studies (Lamb, 1979, 1981), and field studies (Briggs and McDonald, 1978, Briggs, 1985, Briggs et. al, 1986). As a result of the distributions of vertical velocities, the vertical pollutant distribution from an elevated source exhibits a descending mode of highest concentration (the region of highest concentration tends towards the surface) as the plume moves downwind. This contrasts with the mode (centerline) of a Gaussian distribution which remains elevated.

To model the vertical distribution, CTDMPLUS employs a probability density function (PDF) approach based on a method suggested by Li and Briggs (1988). PDF models assume that, in a convectively mixed layer, the Lagrangian time scale is sufficiently large that particles released into the flow will remain approximately on their initial trajectory until the surface or the mixed layer top are reached. Particles initially released into downdrafts remain in downdrafts, those released into updrafts remain in updrafts. For steady conditions, the trajectory of a particle will be controlled by the horizontal flow speed and the vertical velocity at the point of release. Thus, the vertical distribution of pollutant is a function of the probability density distribution of vertical velocities at the source.

The PDF of Li and Briggs (1988) has an asymmetrical bi-Gaussian form that produces pollutant distributions very similar to those observed experimentally by Willis and Deardorff (1981). The bi-Gaussian model produces maximum surface cross-wind integrated concentrations (CWIC) that occurr with approximately the same magnitude and at about the same downwind distance as the observations.

CTDMPLUS contains a modified PDF approach. Normally assumed linear particle trajectories are distorted by the terrain adjusted flow. The model uses the previously mentioned flow algorithm (for flow above the dividing streamline) to estimate the streamline distortions in the well-mixed layer. The model uses an iterative approach (Perry et al., 1989) to find the proper initial vertical velocity that will send a particle through the distorted flow from source to receptor. If a particular receptor is not associated with elevated terrain, the model will return a flat terrain estimate of CWIC as displayed in Fig. 3b.

Adjusted Mixing Height and the Vertical Distribution. The height of the mixed layer, as the flow passes over the terrain, can have a significant influence on the vertical spacing of the streamlines within the layer. The finite depth of the mixed layer (and the adjusted depth) has an effect on the streamlines in the layer; however, this is not accounted for in estimates of flow distortion by the flow model (which assumes no cap to the layer). Therefore, corrections to the flow model based on mixing height deflections were incorporated into CTDMPLUS.

The approach is based upon a recent fluid modeling study by Perry and Snyder (1989). To simulate the mean flow in a daytime well-mixed layer beneath a deep stable layer, they used a two-layer flow (one neutrally stratified and one stable) in the large towing tank at the EPA Fluid Modeling Facility. They measured the vertical deflections of the interface (surrogate for the mixed layer top) between these two layers with flow over the crest of model terrain. Four parameters were identified as significantly affecting the results: z_i (mixing height), H (hill height), U (the tow speed), and N (the Brunt-Vaisala frequency). From these, they established two dimensionless product, $Fr = U/NH$ and z_i/H, which are appropriate for scaling the study results. Terrain shape was also taken into consideration.

For a given initial mixing height, Perry and Snyder found that an increase in the Froude number, Fr, is associated with an increase in streamline deflections, signifying an increased

ability of the flow to overcome the elevated stratification and push over the top of the hill. In contrast to the widely used "half-height" correction factor for adjusting the mixing height in complex terrain by a constant of 0.5, Perry and Snyder show that, in fact, the mixing height adjustment is very much a function of meteorological variables. Over the range of Fr and z_i/H contained in their experiments, they found the "correction factor" to range from 0.1 to 0.9.

CTDMPLUS uses these fluid modeling results to apply a bulk correction to the flow model stratification factor. The adjusted flow model is then used to determine the correct trajectories for the PDF algorithm.

The Horizontal Distribution Function. Since Gaussian horizontal plume shapes are generally observed in convective boundary layers, CTDMPLUS uses the standard Gaussian form for the horizontal distribution function. The flow model determines the crosswind receptor-centerline distance as the distance between the streamline passing through the source and that passing through the receptor.

Recent literature has been generous with parameterizations of the lateral dispersion coefficient applicable to convective boundary layers. The formulations chosen for CTDMPLUS are based on convective scaling concepts and were suggested by Briggs (1985) and Hanna (1986) after separate analyses of power plant field data. Formulas for buoyant and non-buoyant plumes and for short and long travel times are found in Perry et al. (1989).

CTDMPLUS EVALUATION

During the development of the CTDM model for stable/neutral conditions three separate field tracer studies were performed for the purpose of both understanding plume behavior in complex terrain and for evaluating the developed model. These three data sets (described in Strimaitis et al., 1987) include measurements of plume-terrain interaction at an isolated, nearly axisymmetric hill (Cinder Cone Butte, CCB), an isolated ridge (Hog Back Ridge, HBR), and an actual power plant in a mountainous setting (Full Scale Plume Study, FSPS). In addition, two sulfur dioxide monitoring studies in the vicinity of operating industrial facilities were included in the evaluation of the stable/neutral algorithms of CTDMPLUS. These are the Westvaco paper mill study (Hanna et al., 1984; Wackter and Londergan, 1984) and the Widows Creek power plant study (Egan et al., 1985).

Good quality monitoring data for evaluating the CTDMPLUS algorithms for convective conditions are not as plentiful as those for the stable conditions. Preliminary testing and evaluation has been performed on these daytime algorithms with an applicable subset of the Westvaco data base only.

Performance of the CTDMPLUS Stable/Neutral Algorithms

Using each of the five data sets mentioned above, a number of subsets of observed and predicted concentrations were constructed for calculating comparison statistics. These subsets included pairings of observed and predicted values in time only (highest observed at given time compared to highest predicted regardless of location) and unpaired concentrations ranked from highest to lowest and then paired (again using only the highest concentration in each hour).

For the pairings in time only, we selected the following values to give a summary of the CTDMPLUS performance against observations and the EPA-recommended complex terrain screening model, RTDM (Paine and Egan, 1987): the average of the highest concentration for each hour of data; the ratio of this average for the model to that for the observations; the root mean square difference between model predictions and observations; and the percent of pairs where the predictions are within a factor of two of the observations.

Table 1. Summary statistics for data paired in time only (highest concentration for each hour) and for stable/neutral conditions. Concentrations are normalized by emission rates.

Data Base	Model	Avg.	Pre/Obs	RMS Diff	% within a factor of two
CCB(SF_6)	OBS	28.0	---	---	---
	CTDM+	26.2	0.9	28.7	37
	RTDM	36.4	1.3	58.3	27
CCB(freon)	OBS	15.0	---	---	---
	CTDM+	21.0	1.4	29.2	23
	RTDM	11.0	0.7	24.3	50
HBR(SF_6)	OBS	23.5	---	---	---
	CTDM+	47.8	2.0	58.3	37
	RTDM	74.7	3.2	159.9	14
HBR(freon)	OBS	104.3	---	---	---
	CTDM+	49.1	0.5	93.1	57
	RTDM	444.1	4.3	678.3	13
FSPS(SF_6)	OBS	2.0	---	---	---
	CTDM+	1.9	1.0	2.1	61
	RTDM	3.1	1.6	3.4	48
FSPS(freon)	OBS	2.8	---	---	---
	CTDM+	2.5	0.9	2.9	60
	RTDM	3.8	1.3	4.8	39
Westvaco	OBS	0.33	---	---	---
	CTDM+	0.29	0.88	0.83	14
	RTDM	0.98	2.97	2.43	16
Widows Cr*	OBS	71.9	---	---	---
	CTDM	141.8	2.0	403.6	23
	RTDM	322.3	4.5	764.6	7

* Widows Cr$_3$ concentrations are not normalized (units = $\mu g/m^3$)

Table 1 contains the comparisons for the time-paired subsets. For the three tracer studies, there were two gases used; SF_6 and Freon. The SF_6 was generally released near or above the dividing streamline height and the Freon was released, in general, below this height. The concentrations in the table are normalized by the hourly emissions and thus have units of $\mu sec/m^3$.

With the exception of the comparisons for the (low) freon releases at CCB, CTDMPLUS proves superior to RTDM in average prediction error, rms difference, and percent within a factor of two. Also, with all data sets except the freon releases at CCB, RTDM overpredicts on the average and in some cases by a considerable amount (ratios of average predicted to average observed range from 1.3 to 4.5). CTDMPLUS, for the same data sets, on average underpredicts to a small extent in some cases and overpredicts in others (ratios range from 0.5 to 2.0).

For the CCB freon releases where the tracer is generally below the dividing streamline (plume impaction cases) CTDMPLUS tends to overpredict on average by about the same amount that RTDM underpredicts.

Table 2 presents comparisons for the subset of predicted and observed concentrations that were unpaired in time or space. The highest hourly values were selected from the observations and from the two models' estimates; then each set was ranked from highest to lowest concentration and then compared as shown in the table. The CCB and HBR tracer studies were not used for these comparisons because the source and monitor locations were frequently changed throughout the experiment making unpaired comparisons difficult to interpret.

Table 2 indicates that RTDM consistently overpredicts the maximum concentrations by over 40%. CTDMPLUS on the other hand tends to underpredict somewhat in the tracer studies and over predict in the SO_2 studies. A primary difference between the FSPS tracer study and the SO_2 studies was the downwind distance to the

Table 2. Summary statistics for data unpaired in time or space (ranked from highest to lowest) for stable/neutral conditions. Concentrations are normalized by emission rates.

Data Base	Model	Highest	Avg. of Top 10	Pre/Obs*
FSPS(SF_6)	OBS	10.2	8.1	---
	CTDM+	7.2	6.1	0.8
	RTDM	12.9	11.4	1.4
FSPS(freon)	OBS	19.5	12.9	---
	CTDM+	8.9	7.9	0.6
	RTDM	22.0	19.3	1.5
Westvaco	OBS	7.2	5.7	---
	CTDM+	13.6	9.3	1.6
	RTDM	15.4	13.6	2.4
Widows Cr.**	OBS	4609	2627	---
	CTDM+	6857	5435	2.1
	RTDM	4773	4420	1.7

* ratio of the average of the top 10 predicted concentrations to the top 10 observed concentrations.
** Widows Cr. concentrations are not normalized (units = $\mu g/m^3$).

monitors. The travel time in the FSPS study was often two or more times that in the SO_2 studies, suggesting that CTDMPLUS' diffusion rates may be too large for large travel times. In the cases of actual facilities operating near to dominant terrain, both models tend to overpredict the worst impacts.

Performance of the CTDMPLUS Convective Algorithms

Evaluation of the algorithms for daytime convective conditions was accomplished on the Westvaco data base only. The same summary statistics that were used to describe the performance of the stable/neutral algorithms were used for the convective algorithms.

Table 3a displays the results for the pairings in time only (highest observed for each hour paired with the highest predicted). For these pairings we selected another subset for comparing modeled to observed concentrations which includes only the top 198 hours (top 10% as determined by the observed values). This gives an indication of how well the models are doing for the generally higher impact situations.

Table 3a. Summary statistics for data paired in time only (highest concentration for each hour selected) for convective conditions in the Westvaco data. Concentrations normalized by emission rate.

Data Subset	Model	Mean	Pre/Obs	RMS Diff	% within a factor of two
All Data	OBS	0.32	---	---	---
	CTDM+	0.46	1.44	0.82	28
	RTDM	0.16	0.50	0.88	20
Top 10%	OBS	1.42	---	---	---
	CTDM+	0.64	0.45	1.48	29
	RTDM	0.38	0.27	2.08	4

Table 3b. Summary statistics for data unpaired in time or space (ranked from highest to lowest) for convective conditions in the Westvaco data. Concentrations are normalized by emission rate.

Model	Highest	Avg. of Top 10	Pre/Obs
OBS	5.65	4.22	---
CTDM+	5.99	4.53	1.07
RTDM	13.70	8.23	1.95

The distinction between CTDMPLUS and RTDM for convective conditions is absolutely clear. On average, RTDM considerably underpredicts the observed concentrations and rarely predicts within a factor of two (4% of the time) during conditions when the observations are high. On the contrary, CTDMPLUS tends to overpredict the average over all data by about 40% and underpredicts by about the same amount for conditions with higher observed impacts. This change from average overprediction to average underpredict is one indication that CTDMPLUS is finding concentrations similar to those observed but not always under the same meteorological conditions.

Table 3b shows the performance of the models with data unpaired in time or space (and ranked highest to lowest).Here is strong evidence that CTDMPLUS is capable of predicting the highest concentrations for convective conditions; this is important for a regulatory model. However, as shown by the time-pairing results, the model is finding highest concentrations during conditions that do not always coincide with the conditions for highest observed concentrations. RTDM is predicting highest concentrations that are generally about twice as large as the highest observed values and is also finding its highest concentrations during meteorological conditions that do not always coincide with highest observed conditions.

Figure 3 shows the relationship between the ranked observed concentrations and the ranked model concentrations for the top 1% of the data tested.

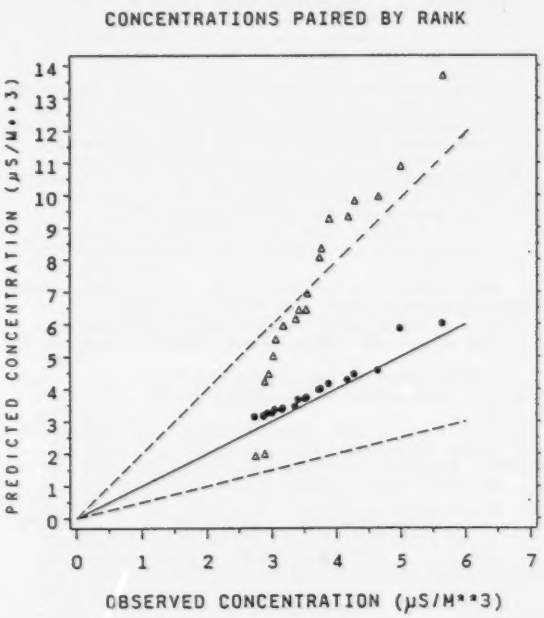

Fig. 3. Comparison of the model predictions to observations at the Westvaco site for concentrations unpaired in time or space, then ranked from highest to lowest (top 1%). The solid line represents a one-to-one comparison and the dashed lines represent predicted/observed ratios between 0.5 and 2.0 (factor of two).

CTDMPLUS shows superior performance to RTDM for finding highest concentrations during convective conditions at the Westvaco site. Most importantly, this figure shows that CTDMPLUS is providing predictions that cover a range of values similar to the observations, whereas RTDM yields a much larger range than that observed.

SUMMARY

The CTDMPLUS point-source, steady-state, dispersion model for complex terrain applications has been described and its performance discussed. The model is unique particularly in the manner in which it simulates the flow (and plume) distortion

near the terrain. Simplicity is maintained by applying flow distortion corrections to the flat terrain Gaussian and bi-Gaussian pollutant distributions.

The evaluation of CTDMPLUS is quite conclusive. In stable or neutral conditions, CTDMPLUS shows varied but relatively small average bias over the five data sets considered. The model tended to overpredict, on average, for some situations and underpredict in others with the average prediction always within a factor of two of average for the observations. The root-mean-square differences for CTDMPLUS were consistently lower and the percent of paired values within a factor of two was significantly higher than those of a currently approved regulatory model.

In convective conditions, CTDMPLUS overpredicts on average by about 40% and for time pairings underpredicts during the hours of highest observed concentrations by about a factor of two. However, with the unpaired data (regulatory mode), CTDMPLUS performs very well

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